Influence of Social Intention on Switch Cost in Task-Switching Paradigms

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Abstract

Humans have built a society based upon elaborate social interactions. We have processes that enable us to interact with each other and switch between tasks. Humans often multitask especially in a social context, such as talking while working on a project, listening to someone while driving, or switching between conversations with different people. One of these processes that aids in this interaction is the intentional stance. The intentional stance is the tendency humans have to view other's actions as driven by their own mental states, beliefs, and intentions. In this experiment, it is examined whether or not social cognition, such as inferring the beliefs or intentions of others, behaves like other cognitively dominant tasks. Cognitively dominant tasks are automatic processes that are elicited with minimal to no effort, such as reading. A task switching paradigm was used among two groups, social and non-social, where tasks in the social group invoke the intentional stance and tasks in the non-social group do not. Switch cost, the increase in reaction time when switching between tasks, may increase when switching from a hard task to an easier task. This is due to the amount of inhibition initially placed on the easier stimuli in order to attend to the cued, more difficult stimulus until the more readily available stimulus has become relevant again Based on previous research, it is believed that switching from a non-social to a social task will result in a greater switch cost due to the amount of effort needed to overcome inhibition initially placed on the more readily available stimuli, or the social stimuli. These findings would support the hypothesis that social cognitive process behave similarly to other cognitively dominant processes.

Introduction

Humans are extremely social beings with even more complex social behaviors. They have a social relationship with their environment that heavily influences individual behavior and may be adaptively predisposed to engage in social cognitive processes. Numerous cognitive processes are known for their ability to adapt to changes in one's environment. Task switching paradigms measure an individual's ability to rapidly shift one's attention between tasks by comparing reaction times between trials. For example, in Arrington, Altmann, and Carr's 2003 study on similarity effects, participants were presented with a rectangle that varied in dimension and color. The cues, either "height," "width," "color," or "brightness," indicated to which characteristic of the rectangle participants would respond. Trials could repeat by asking participants to complete the same task as the previous trial, such as cueing "color" two times in a row. Alternatively, trials may switch and cue a different task than the one before. Switching from one task to another evokes a switch cost. Switch cost describes the "cost of transitioning tasks" that results in a delay in reaction time for that trial. Previous studies show that task-switching increases both reaction times and error rates when compared to repeat trials (Arrington, Altmann, & Carr, 2003). Alternating between tasks results in a time-consuming executive control process, and the brain must reconfigure the task-set in order to produce the correct response (Strobach, Wendt, & Janczyk, 2018).

Executive functions are voluntary, consciously controlled processes that help regulate cognition such as inhibitory control, updating working memory, and shifting. Though executive functions are typically considered effortful, an increasing amount of evidence proposes that executive functions may be automatically triggered even in social context (Dudarev & Hassin, 2016). Research also shows that there exists a positive correlation between executive control functioning and Theory of Mind (ToM, sometimes called mentalizing) skills, where executive control might be a prerequisite for mental state inferences (Saxe, Schulz, & Jiang, 2006). Social cognition processes are mediated by the Theory of Mind network, a group of brain regions that control the interpretation of intentions, desires, perspectives, and how they may differ from one's own emotions. The Theory of Mind network is vital to the development of behavior interpretation and prediction (Gweon & Saxe, 2013). Developing accurate representations of social interactions allows one to adjust their behaviors accordingly.

One important aspect of this type of social processing is the *intentional* stance. The intentional stance is when individuals interpret the behavior of others based on the idea that their actions are governed by intentions, beliefs, and other mental states (Dennett, 2009). The intentional stance can apply to varying forms of communication, such as facial expressions, speech, general actions, and hand gestures (Kelly et al., 2007, Pavlova, 2011). Although processes like determining how to act on communicative stimuli were largely considered to be high-level and intentional, how we process incoming social information may possibly be automatic.

As more studies of the Theory of Mind network have been published, it has become increasingly apparent that there is an overlap between parts of the Default Mode Network (DMN) and regions activated during tasks that ask participants to infer belief and intentions of others (Andrews-Hanna et al., 2014, Spunt et al., 2015). The DMN is an interconnected group of brain regions that are active when participants undergoing functional magnetic resonance imaging (fMRI) are resting without focusing on any given task (Buckner et al., 2008). Functional magnetic resonance imaging is used to measure brain activity by measuring blood oxygen level dependent (BOLD) signals, blood oxygenation and flow, in the brain. The DMN has been observed to primarily consist of the medial prefrontal cortex (mPFC), temporoparietal junction (TPJ), dorsomedial PFC (dmPFC), as well as a few other subsystems identified in numerous neuroimaging studies (Andrews-Hanna et al., 2014). The mPFC has been found to play a crucial role in the social understanding of other individuals, or the comprehension of social cues and feelings of empathy, while the TPJ is crucial for attributing mental states, the process of distinguishing between one's own emotions and needs versus the feelings of someone else (Li et al., 2014, Mars et al., 2012). The DMN shows patterns of deactivation during tasks requiring external attention, such as attending to people in our social world (Anticevic et al., 2012).

Tasks in studies that observe DMN activation related to the intentional stance include determining the emotional expressions of facial stimuli, asking participants what they would do when faced with a moral dilemma, punishing individuals for violating social norms, and a multitude of other techniques (Atique et al., 2011; Padmanabhan et al., 2017; Pujol et al., 2011). The overlap in the physical networking of both the DMN and social processing may suggest some sort of functional relatedness. Andrews-Hanna and colleagues predicted that self-generated thoughts, or those which are directed internally like recalling memories and mind wandering, produced by the DMN prepare individuals for social events (2014). A recent study from Meyer, Davachi, Oschner, and Lieberman in 2018 suggested that mPFC and TPJ activity during rest allows for automatic consolidation of new social information. Thoughts are often future-focused or involve some form of goal-oriented, autobiographical planning. Thus, DMN activity from this inward thinking may drive a human's ability to form responses to social interactions, engage with others, and better govern one's own actions.

Humans have constructed an elaborate social network in our environment. Because of the emphasis placed on social interaction, it is believed that social intention may behave like other dominant cognitive processes. The purpose of this study is to examine how social intention affects task representation and what other aspects of task similarity affect task switching, as well as how social intention compares to other cognitively-dominant processes. Understanding the mechanisms and neural networks behind social cognition is critical to understanding others' thoughts, actions, and personalities. Psychotherapies can be focused to possibly aid individuals with different neurological disorders, such as schizophrenia or autism, both of which may affect the acquisition of social skills. Our lab proposes a hierarchical task switching paradigm of non-social and social tasks, in which participants make social judgments on the intentions of individuals, given an image of an actor reaching for different objects. The described task-switching paradigm will test the hypothesis that social processing is automatic, and the study will provide behavioral support for intentional stance priming.

Literature Review

A social approach to task-switching has been severely underrepresented in literature, despite task-switching being an extremely popular subject of research. Over 730,000 studies with task-switching as a key word have been published in the last 10 year. Typical task-switching paradigms have two possible trials, a repeat (nonswitch) condition or a switch condition. When an individual must switch over from one task to another, it requires additional cognitive processes than if the individual were continuing with the same task (Kiesel et al., 2010). Task transitioning results in an increase of reaction time for the switch trial, where the switch cost quantifies this as the difference in reaction time between repeat trials and switch trial. For example, switch cost may occur when asking consecutive questions about a rectangle's height; but if this is followed by a question asking about the rectangles hue, reaction time increases.

Dominance of a task is best demonstrated by the Stroop Task, where participants were simultaneously presented with conflicting stimuli: the name of a color with the font in the ink of a different color (Stroop, 1992). Participants were asked to say the color of the word, and not to read the printed word. During trials where the ink of the word matched the word itself, reaction times were significantly faster than trials where the ink did not match the word. Reading is a dominant process that demands very little attention or working memory, and improves through practice or repetition. This automatic behavior interferes when asked to identify the color stimuli compared to the word stimuli while completing the Stroop Task.

A task transition requires additional cognitive processes. One might expect that switching from a hue trial to a height trial would result in the same switch cost as switching from a height trial to a hue trial, however; this is not always the case (Arrington, Altmann, & Carr, 2003; Kiesel et al., 2010). A symmetric switch cost occurs when the reaction time difference is the same no matter which task is switched to or from. An asymmetric switch cost arises when one task within a task pair is more dominant or easier. Neural mechanisms that arise when switching between tasks of unequal dominance, such as inhibitory and endogenous control, lead to a asymmetric differences in reaction times, or an asymmetric switch cost. Reversed asymmetry is when switching to the easier task incurs a smaller switch cost. Researchers commonly agree that in reversed asymmetric switch cost cases there may exist some sustained activation or endogenous priming that produces a smaller switch cost (Allport & Wylie, 1999; Schneider & Anderson, 2010). The easier task representation facilitates improved performance which leads to a smaller mean switch cost. Typically, one would assume that switching to an easier task would result in a decrease in reaction time compared to the previous trial, but this is uncommon. The most common type of asymmetry, surprising asymmetry, happens when a larger switch cost occurs when switching to an easier task; this is unintuitive to what one would expect to happen when switching to an easier task. It is believed that the reason for this is due to sustained inhibition of the dominant task set, or the task-set inertia, the participant must inhibit the readily available easy task, and in turn, the large amount of inhibition takes more time to overcome for the easier task (Allport, Styles, & Hsieh, 1994). Using the Stroop task as another example, participants must suppress the “easy” information, reading the word, and focus on the “hard” task of saying the color of the word. Generally, in order to perform well on a harder task, one must strongly inhibit the readily available easy task. When an individual is cued to pay attention to the easy task after a period of forcibly not focusing on the irrelevant information, it takes considerably more time to overcome the inhibition when it is relevant again.

Other studies aim to explain asymmetry through task similarity rather than inhibition or priming. In Arrington’s study, participants were asked four two-choice discrimination tasks about height, width, color, and brightness (2003). Height and width both discern the rectangle’s dimension while color and brightness are both prompts based on the rectangle’s color. The similarity in task components affect the cognitive processes required for task switching. Though asking the height of the rectangle is different than asking about the width, they still share attentional control aspects that focus on the dimension of the rectangle. Dually, hue and brightness are two different tasks but both inquire about the color of the rectangle. Using the task similarity approach, trials that switch between similar task can conceptually be considered a repeat trial for either color or dimension even though it is a switch trial for the task itself. Task similarity had a statistically significant effect on switch cost, where switching between similar tasks resulted in 61 milliseconds faster mean reaction times compared to switch costs between dissimilar tasks (Arrington, Altmann, & Carr, 2003). Task similarity explains the magnitude of the differences in reaction times, while task set inertia focuses on the pattern due to the differences in dominance of the tasks.

This raises the question: Are there other components to task switching that affect switch cost? Society puts a massive emphasis on social relations that we navigate using task switching. Individuals interact with other people who have different beliefs, thoughts, and ideas that they must infer. People switch between their own mental state and inferring others' when interacting with those around them. Humans inherently take on an intentional stance, a strategy used to interpret the behaviors of others that are guided by intentions, beliefs, and other mental states (Dennett, 2009). The Default Mode Network becomes active during periods where cognitive activity declines which can be observed using an fMRI to measure BOLD signals in correlated regions of the brain (Buckner et al., 2008). The medial prefrontal cortex (mPFC) is a key region of the DMN but also serves a role in social perceptions, for example, understanding others and emotional engagement (Li et al., 2014). The mPFC is one subregion of the mentalizing network, or the Theory of Mind network, which is a network responsible for inferring mental states of other humans, such as their desires, intentions, and beliefs (Saxe, 2009).

Only recently has investigation into the relatedness of the DMN and mentalizing network begun to produce promising results explaining their interconnectedness. In 2015, Spunt et al. found that baseline DMN activity among individuals, primarily the dorsomedial prefrontal cortex, predicted ease of implementing the intentional stance and reduced, accurate response time towards social stimuli. Participants in Spunt's study were asked "yes" or "no" questions related to mind-focused, body-focused, and math-based stimuli. In mind-focused trials, participants were to infer the correct answer from the statement. For example, in a mind-focused trial an image of a child reading a book is depicted along with the statement "he is gaining knowledge" and the participant would state whether or not they agree. For the body-focused trial, statements such as "he is baring his teeth" were shown with an image of a man showing his teeth. Non-social judgments, or math equations, were also presented and asked if simple mathematical equations were correct or not. Mind-focused trials were found to provoke the intentional stance, while body-focused trials did not. Greater DMN activity during the fixation period before mind-focused trials corresponded with faster reaction times on subsequent trials. Even though participants produced more accurate and faster responses for body-focused trials than mind-focused, this priming effect only existed for the mind-focused trials.

Our lab proposes to use task switching paradigm between social and non-social stimuli to test whether intentional stance processing is a dominant process (and thus require more inhibition to switch away from). Because our hypothesis is that the intentional stance will act similarly to other dominant processes and require a larger amount of inhibition to overcome, we expect that a larger switch cost will occur when switching from a non-social to a social task.

Methods

Procedure

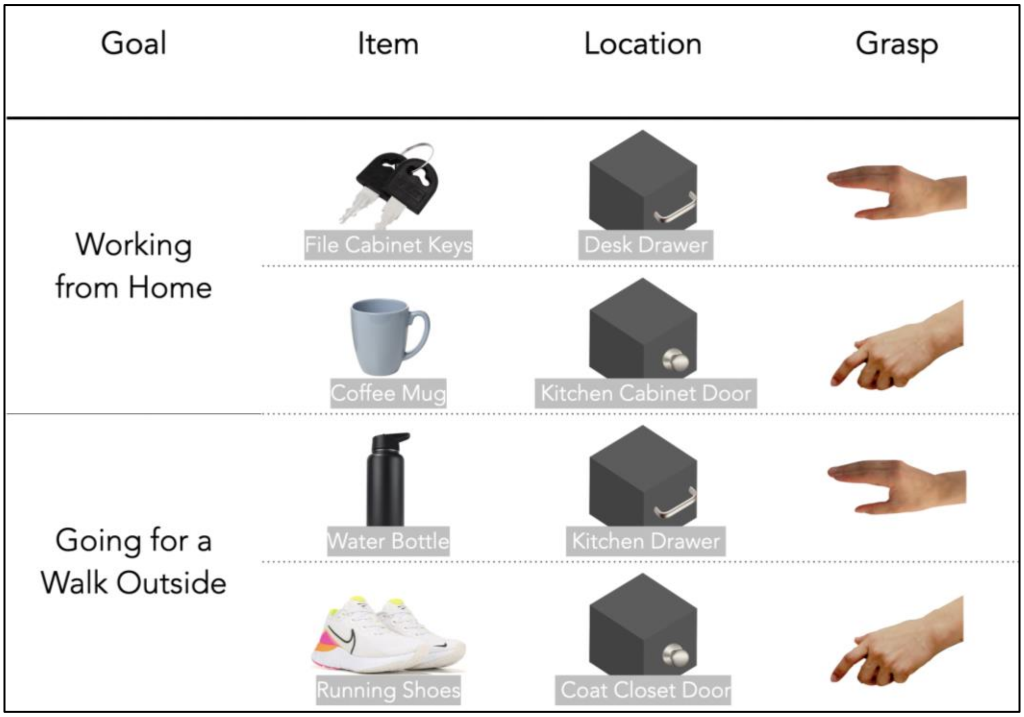

Figure 1: Visual Summary Table. The figure shows the visual summary table presented to the Social group. The Non-Social group will not be shown the Goal column.

After written informed consent is obtained, 150 subjects will be recruited for the experiment through Georgia Institute of Technology's SONA program. Participants will be randomly assigned into either the social group or the Non-Social group. Participants will complete a task switching procedure that contains social or Non-Social stimuli. Participants will be randomly assigned to either the social stimuli group, which will compare data from both social and non-social trials, or a non-social control group that contains only non-social stimuli. Before each block, a visual summary table will be presented to the participants.

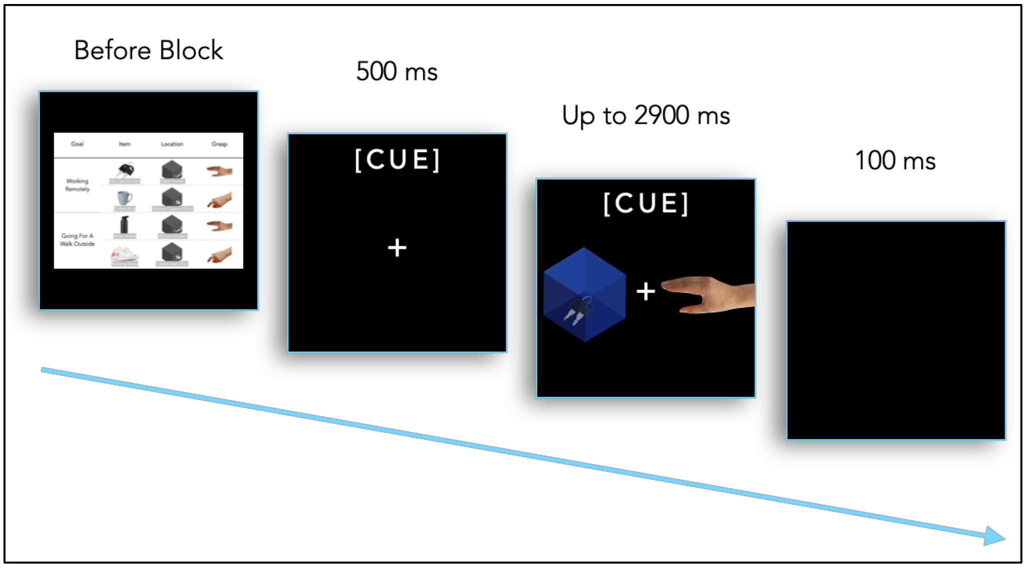

Figure 2: Trial Design. The figure shows what a trial would look like for the participant.

During the trials, participants will see a fixation cross for 500ms followed by a static image of a hand reaching for a colored box with an item inside. The images and cues will stay on the screen for up to 2900ms during the response period and will be followed by a blank, black screen for 100ms. Grasping positions of the hands will change according to the item's location. For example, reaching for a knob will have a different grasp than reaching for a handle. However, the handles will not be visible during the trials themselves. Participants have one of four possible cued tasks that they will have to complete for each trial. These tasks will change depending on whether they are in the Social group or Non-Social group. Both groups will be asked to make judgements on the brightness, light or dark, and color, green or blue, of the box. The chosen colors and design replicate Arrington's 2003 experimental procedure. Color and brightness tasks do not invoke the intentional stance and are deemed "non-intentional" tasks. The intentional stance provoking stimuli will ask participants to infer goals and actions. The table informs participants that there are two goals, with two actions needed to complete each goal. For example, to go for a walk outside one must obtain both the water bottle from a drawer and their shoes from behind a door. The table ensures that there is one objectively correct answer for each Goal trial and Action trial. As previously stated, the handles will not be shown for the trials. Participants will have to infer from the grasping action how the stimulus is interacting with the box object. The participant will have to remember where a certain item is or how the hand is positioned to open either a door or a drawer. For a task goal, objects are always associated with being located in a drawer or door. Both Action and Goal tasks change with the item's identity. Items and Goals change each block so that participants do not memorize any information and make associations that do not require inference of social intention. Participants will make judgements on either the task that the image is portraying or the action itself. The Goal task may be "getting dressed," showing a hand reaching for a sock drawer, while the Action task is "reaching for the drawer".

For the non-social group, goal and action tasks will not be asked, but instead more questions about the image itself will be cued. These will not ask the participant to infer any intentions but will ask about the size of the image and its orientation. For example, the standard stimulus size may be noticeably smaller. Similarly, the orientation of the image may flip showing the hand approaching the box from either side. Size and orientation will not change at all in the social group's stimuli. Participants in the non-social group will also be provided a visual summary table but will not be shown the goal column. Non-social tasks that still show these images act as a control for the social group to account for a participant's possible ability to automatically process social intent even at a more abstract level without being provided any cues.

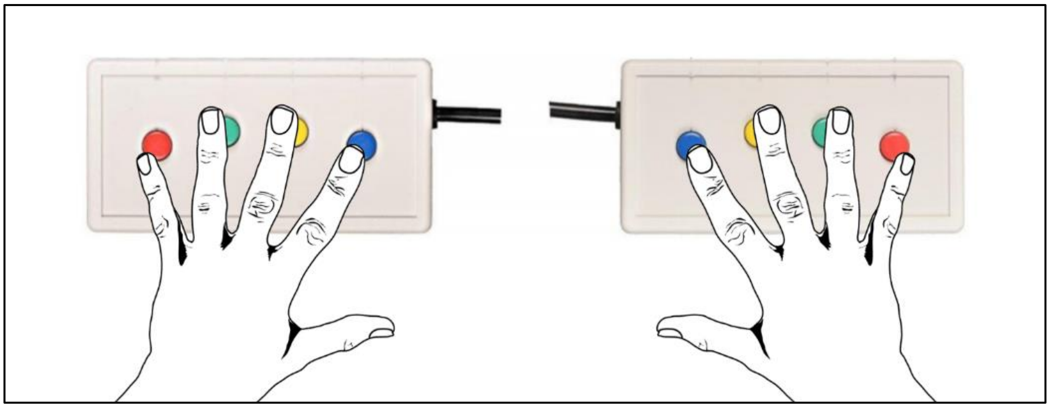

Figure 3: Orientation with Button Boxes. The figure shows how a participant will orient their hands.

To input their answers, participants will use two button boxes, each having four buttons. For both groups, the index finger will be used to select rectangle hue and the middle finger will be used to differentiate color. In the social group, the ring finger will be used to select the action (opening a drawer or opening a door) and the pinky will select the task (going for a walk or getting dressed). In the non-social group, the ring finger will be used to select the size of the rectangle cue (large or small) and the pinky will select the side the cue appears on (left or right). Prompts as to which response is required will appear above fixation cross before the stimulus appears. For example, the word “Color” would appear above the fixation cross, the rectangle will be shown, then based on whether the rectangle is tall or short, the participant will use their middle finger to either select “blue” or “green”.

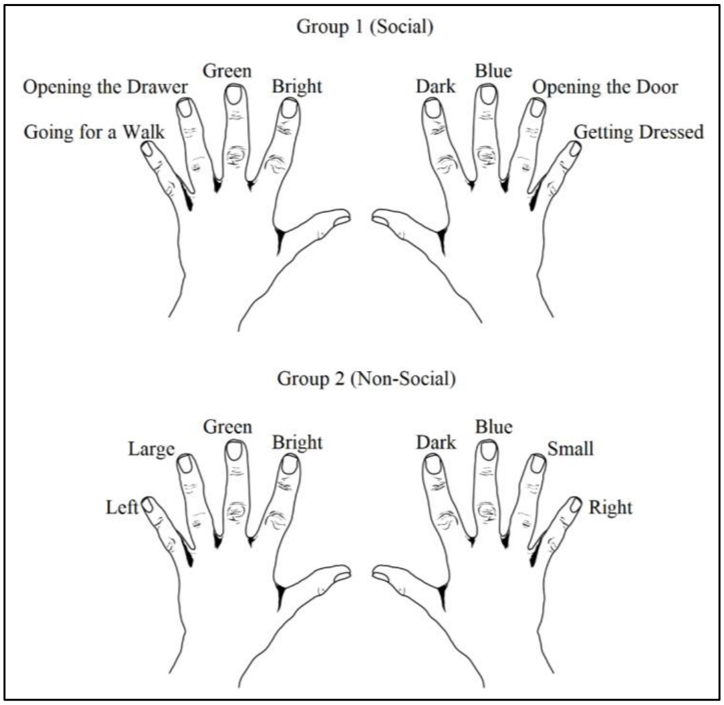

Figure 4: Finger Orientation. The figure shows which finger responds to each stimulus prompt.

Trials will be a mixture of repeat and switch trials. Repeat trials will ask about the same stimuli attribute, such as asking about the color of the stimuli for two sequential trials. The color between trials may change, but this is still considered a repeat trial because the question being asked does not change. Switch trials will ask about a different attribute.

The design of this experiment compares tasks based on similar components, such as the intentional task set as well as the color task set. Color and hue trials are grouped under the color task set, while action and goal tasks are considered part of the intentional task set. Non-social questions that ask about the image size and orientation are part of the image task set. The image task set is comparable to the intentional task set in that both share similar perceptual encoding. This way, the influence of social intention and how it affects task representation by comparing switch costs is easier to analyze.

Behavioral Data Acquisition and Analysis

Variables of interest include response time, accuracy, task, task type, trial type, and switch trial type data which will be collected on a computer using Eprime™ software. The task itself is responding to the proper question about the stimuli's attributes, and the task type is whether or not the cue is social or non-social. The trial type will either be non-switch, or congruent with the previous trial, or switch, where the questions between trials will switch from a social to a non-social question or vice versa (switch trial type). The variables that will be analyzed are response time, accuracy, and switch cost. A repeated measures ANOVA will be used to test for effects between, task, task type, trial type, and switch trial type on switch cost, accuracy, and response time. Outliers, data that is not within 3 standard deviations of the mean response time, will be excluded from the analysis in order to avoid skewing the data.

Discussion and Broader Impacts

The current design allows similar tasks to be grouped together based on their content. This way, it is possible to analyze the influence of social intention on task representations by comparing the patterns between switch cost. Both color and image task sets will be compared to intentional task sets. It is expected that the non-social group will have an asymmetric switch cost between non-social color tasks and non-social image tasks where the image task set will have greater mean reaction times. Because social processing is predicted to be a dominant process that will require inhibition, switching to the non-social image tasks from a non-social color task will require more time to overcome the inhibition. Switch cost should partially be compensated by the task similarity effect. Size and orientation are also more complex variables than hue and brightness, and thus are expected to have increased reaction times. The non-social group is essentially a replication of Arrington's task-similarity study, and acts as a control for the social group. Similar results to Arrington's study are also expected, or about a 61ms switch cost between task sets. As proposed by Spunt, mental state inferencing would act more dominantly due to the priming effect of the DMN (2015). A disproportionate amount of inhibition would be required in order to correctly answer a non-social task, but would be even more difficult to overcome the inhibition when social inferencing is once again relevant.

Executive functions are effortful and require a majority of our mental resources; however, if social tasks unconsciously recruit execute functioning, then there may exist some evidence that social intent is a dominant process. The reason might be due to an evolutionary development; that humans are pre-adaptively attuned to social cognition. An asymmetric switch cost would also provide behavioral evidence of priming for the intentional stance. This process is heavily associated with mental state reasoning but may also serve as an adaptive function for humans. Results from this study may distinguish a biological basis for individuals to adopt the intentional stance as an effect of living in a social world.

Results would be consistent with existing studies, and that executive control is likely required to infer the intentions of others while simultaneously acting automatically. Task set inertia, from Allport's 1994 study, explains the asymmetric cost pattern between social and non-social stimuli, due to sustained inhibition of the dominant task set. In this study, social tasks were considered to be dominant and autonomous. The difficulty in surpassing this repression is one of the reasons we expect greater switch cost. It is also expected that similar tasks will have minimum switch cost due to shared cognitive components and attentional control processes (Arrington, 2003).

Applications to daily life may demonstrate a human's ability to adapt to their social environment. Humans are raised via the processes underlying the intentional stance. From early childhood, they attempt to explain the behavior of others, and by the time humans reach adulthood they are experts in mental attribution. Adopting the intentional stance in social situations is autonomous and a readily available strategy. Others are automatically viewed as having motivations driven by beliefs and ideas. By being able to identify under which conditions humans take on the intentional stance and the mechanisms behind social inferencing, can lead the way to significant everyday developments. Whether it be through more targeted therapies for individuals with social cognitive deficits or analyzing how a human may adopt the intentional stance towards a robot, being able to apply the process of mental attribution paves a path for future innovation.

Though there is ample evidence of the physical overlap between the DMN and Theory of Mind network, there exists little literature that delves into the functional relatedness of the two systems. Future experiments should determine functional relatedness through fMRI diagnostics. Determining the neurophysiological and functional overlap of the DMN and higher level social cognitive processes is a gap in current literature that requires further attention. Researchers are now interested in observing functional connectivity (FC), the temporal correlation of spontaneous BOLD signals between brain regions; as well as effective connectivity (EC), or the influence of one neural structure over another, of the DMN and mentalizing network (Wierenga et al., 2015; Stephan & Friston, 2010). Kim and colleagues found that fMRI data from low-empathy individuals, individuals that typically have a lack of emotional intelligence and do not pick up on social or emotional cues from others, demonstrated lower FC of the mPFC and anterior cingulate cortex in the DMN (Kim et al., 2017). These results imply that empathy, an important social process required for responding appropriately to different social states, is related to the DMN. However, using FC methods is complicated due to single brain regions being utilized in various different processes; concurrently, the more complex a process is the higher the chance that it will recruit several brain regions (Poldrack, 2011). For example, subregions of the mPFC conduce specialized functions based upon their different roles in subsystems of the DMN; the ventral mPFC is correlated with emotion engagement, the anterior mPFC allows for the distinction between self and others, and the dorsal mPFC in the comprehension of others' mental states (Li et al., 2014). Different tasks from each of these fields have demonstrated some level of connectivity with the DMN, and as task complexity increased so did involvement of related regions of the medial frontal cortex (Li et al., 2014).

Dysfunction of the DMN has also been associated with poor social skills, for example, in a study that observed patients with moderate-severe traumatic brain injury (TBI), it was found that resting-state functional connectivity strength in the DMN could predict social cognition abilities (Llancaster et al., 2019). In Llancaster's study, individuals with a TBI could not recognize emotion as accurately as the neurotypical group. This modified pattern of DMN activity is consistent with findings focusing on individuals with disorders such as depression, autism, and schizophrenia, all of which demonstrate some form of social cognition deficit (Fox et al., 2017; Jung et al., 2014; Sambataro et al., 2013). Individuals that possessed traits linked to the autism spectrum were shown to have demonstrated lower functional connectivity in the DMN during resting state; however the research did not express if this pattern was limited to individual differences amongst those with autism or if opposite patterns could apply to those of the neurotypical population (Jung et al., 2014). Through both neurotypical as well as atypical studies, DMN activity is directly correlational to social functioning. Controlled modulation of the

DMN through mindfulness, a method of therapy that aims to promote thoughtfulness and acceptance of oneself, and meditation are beneficial to those with depression, anxiety, and schizophrenia (Simon & Engstrom, 2015). If evidence is found that the DMN primes for the mentalizing network, it may identify subsystems of interest as possible therapeutic targets for individuals with social cognition deficits.

Though this study emphasizes the possible ramifications that could assist in targeting therapies for individuals with specific social cognitive deficits such as TBI, depression, and autism; it could also be used as a baseline to understanding different social priming among diverse cultures and societies. Previous studies show differences in brain volume dependent on socio-cultural orientation (Huang et al., 2019). Is social priming a relative constant among all cultures or is it dependent on the society in which individuals live in? Having a better understanding of possible unique social priming may advance communication capabilities above the traditional verbal and physical level.

Conclusion

In this study, the influence of social intention on task switching will be observed and tested the hypothesis that social processing is dominant and automatic will be tested. It will provide behavioral support for intentional stance priming. A hierarchical task switching paradigm of non-social tasks and social tasks that asked participants to make inferences about the stimuli’s actions will be used. Through this method, we will be able to analyze how social intention may influence task representations by comparing switch cost patterns. We predict that pattern differences across groups where there is an additional social intention component will provide evidence for the automaticity of intentional stance. A larger switch cost is expected to be found when switching from a non-social task to a social task, which is believed to be due to mental attribution being a dominant process and thus requiring a fair amount of inhibition to suppress. When asked about a social stimulus, it takes more mental effort to surpass this inhibition, resulting in a greater switch cost. Similar tasks should be found to result in little to no switch cost and have similar reaction times among their task set.

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